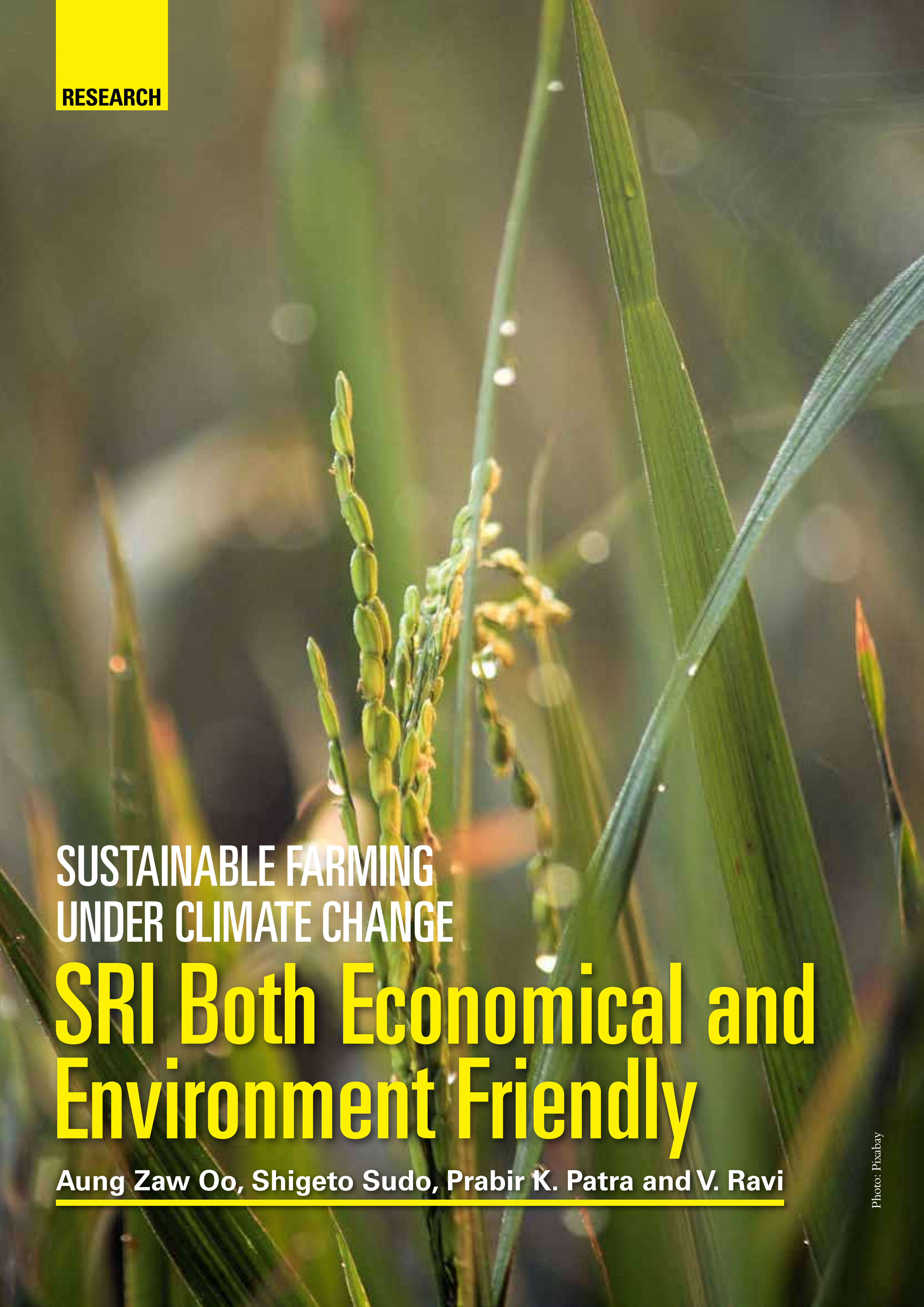
RESEARCH



SUSTAINABLE FARMING UNDER CLIMATE CHANGE

SRI Both Economical and Environment Friendly

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Rice (Oryza sativa L.), the staple food for many Asian countries like China, India and Japan for thousands of years, has faced major production challenges in recent years. They include water scarcity for irrigation, environment pollution and the on-going climate change. Given the methane (CH_4) emissions by rice paddies, rice cultivation itself feeds back into environmental pollution through production of ozone (O_3) in the troposphere. Ozone, being toxic, often causes reduction in rice yields by affecting soft paddy-plant tissues as the stomata opens during photosynthesis[1].

Methane has made the second largest contribution, after carbon dioxide (CO_2), to global warming among the man-made greenhouse gases during the past century. Thus, CH_4 is considered as one of the important short-lived climate pollutants (SLCPs) targeted for immediate mitigation by the Climate and Clean Air Coalition under the United Nations Framework Convention on Climate Change[2].

In a research project to assess the emission reduction potential of Indian rice fields, "Atmospheric Methane and Agriculture in South Asia (AMASA)" that was supported by the Environment Research and Technology Development Fund (A2-1502) of the Ministry of the Environment, Japan with the Tamil Nadu Agricultural University providing support for conducting of the experiments, the authors launched a field observation.

Modifying current cropping techniques is considered to be a possible way for increasing yield, saving water and mitigating greenhouse gas emission. Figure 1a shows that about 14 per cent of total anthropogenic CH_4 emissions are released from rice cultivation in 2003-2012, as estimated by the Emissions Database for Global Atmospheric Research (EDGAR), release EDGAR v4.3.2 (EDGAR, 2016)[3]. The enteric fermentation in ruminants is identified as the single largest (51 per cent) sector of anthropogenic CH_4 emissions, followed by the waste water management (18 per cent).

India has the largest rice crop area harvested and is second only to China in terms of CH_4 emissions in 2014 (*Figure 1 b,c,* page ~~24~~), as per the statistics of the Food and Agriculture Organization of the United Nations[4]. In India, paddy cultivation occupies about 43 million ha (mha), the largest rice producing area in Asia and accounting for 20 per cent of all world rice production.

India's rice production has increased to 157 million tonnes (mt) in 2014 from 53 (area = 35 mha) and 112 (area = 43 mha) Mt in 1961 and 1991 respectively. This is likely to increase to meet the growing demand in the future[5]. Thus, an evaluation of trade-offs between rice yield increase while controlling CH_4 emissions is urgently needed by cropping technique innovation.

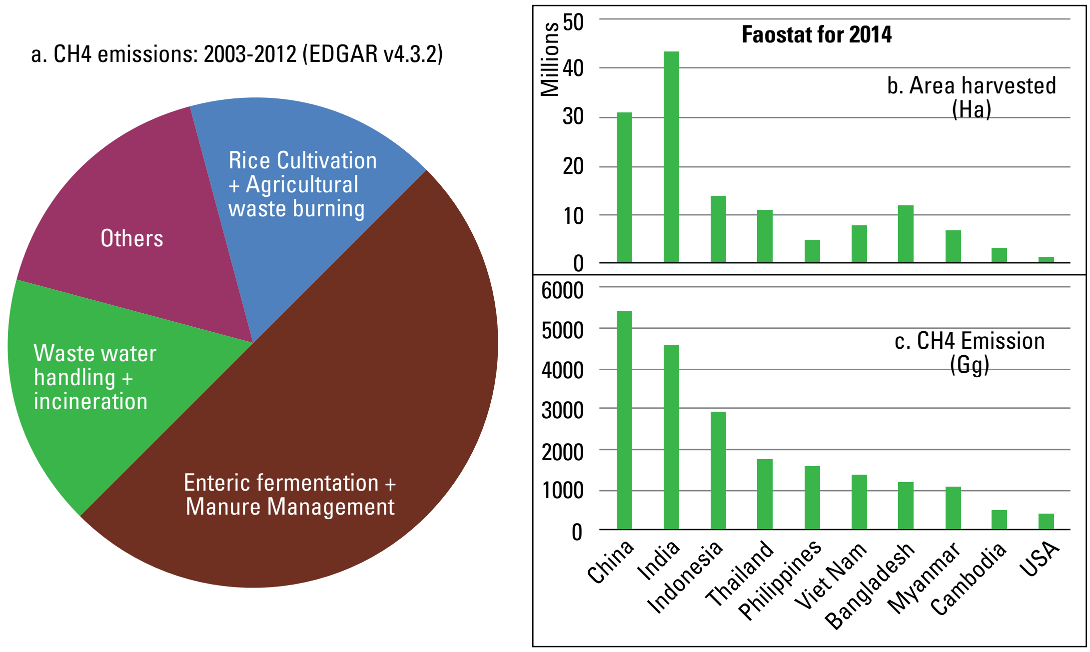
The system of rice intensification (SRI) has been pioneered as a strategy for more efficient, resource saving and productive way to practice rice farming in Madagascar[6]. In contrast to the conventional transplanting (CT), SRI involves reduced water application and transplanting young single plant per hill with wide spacing (*Table 1*) and leads to

Table 1: Three Most Popular Rice Growing Methods

Conventional Transplanting **(CT)**	**ON-CF** **O**ld seedlings, **N**arrow spacing, **C**ontinuous **F**looding
System of Rice Intensification **(SRI)**	**YW-AWD** **Y**oung seedlings with one seedlings per hill, **W**ide spacing, **A**lternate **W**etting and **D**rying
Modified System of Rice Intensification **(MSRI)**	**IB-AWD** **I**ntermediate **B**etween them **A**lternate **W**etting and **D**rying

1 Sawada and Kohno, 2009
2 http://newsroom.unfccc.int/lpaa/short-term-pollutants/
3 EDGAR, 2016; Janssens-Maenhout et al., 2017
4 FAOSTAT, 2016; www.fao.org/faostat/en/#data/GR
5 Carrijo et al., 2017; Hadi et al., 2010; Das and Baruah, 2008
6 De Laulanié, 2011

Figure 1: (a) Emissions from agricultural sectors of enteric fermentation (14910 Gg) and manure management, rice cultivation and agricultural waste burning (4135 Gg) as estimated for the period of 2003-2012 by the EDGAR (2016). (b, c) The area of rice crop harvest and CH_4 emissions for top-10 emission countries in 2014 as per the FAOSTAT (2016).



In modified system of rice intensification, 2-3 seedlings are planted per hill with the same plant spacing of the SRI method to increase the initial transplanting population

a reduction in CH_4 emission though there are reports of little gain in yield and even negative results[7]. This is likely due to the sparse initial population arising from single-seedling per hill at transplanting.

Therefore, a modified pattern of system of rice intensification (MSRI) is introduced, in which 2-3 seedlings can be planted per hill to increase initial population at transplanting with the same plant spacing of the SRI method. Both the SRI and MSRI methods require fewer seeds. The other unique SRI feature is the water management practice of alternate wetting and drying (AWD) cycle.

AWD irrigation can save irrigation water without any loss of rice grain yield while reducing CH_4 emission from rice soil. Despite the advantages of using AWD irrigation practice, it is not easy for farmers to decide the best time to irrigate their crop. The International Rice Research Institute (IRRI) and Institute for Agro-Environmental Science (NIAES) developed a set of simplified guidelines for AWD irrigation system using a field water tube to monitor the water level below the soil surface[8]. A perforated field water tube is used so that the water table is easily visible. Irrigation is advised when the perched water table falls to a threshold level of 15 cm below the soil surface without harming the rice paddies.

Figure 2 shows the field experimental site at the Tamil Nadu Rice Research Institute (TRRI), Aduthurai, Thanjavur District, Tamil Nadu, India (11°0'N, 79°30'E, 19.4 m MSL). Measurements were carried out from May 2016 till January 2017, covering the two rice growing seasons; the hot and dry summer season (Kuruvai: May to September) and the wet and cool monsoon season (Thaladi: September to January). The agro-ecological conditions in the area was a tropical wet and dry/ savanna climate, with a pronounced dry season in the high-sun months and wet season in the low-sun months with annual precipitation of 1292 mm in 2015 (*Figure 2*).

7 Chapagain et al., 2011

8 Minamikawa et al., 2015

Figure 2: Time series of daily minimum and maximum temperature, and rainfall as observed at the experimental site at the Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur district, Tamil Nadu, India (11°0′N, 79°30′E,19.4m MSL).

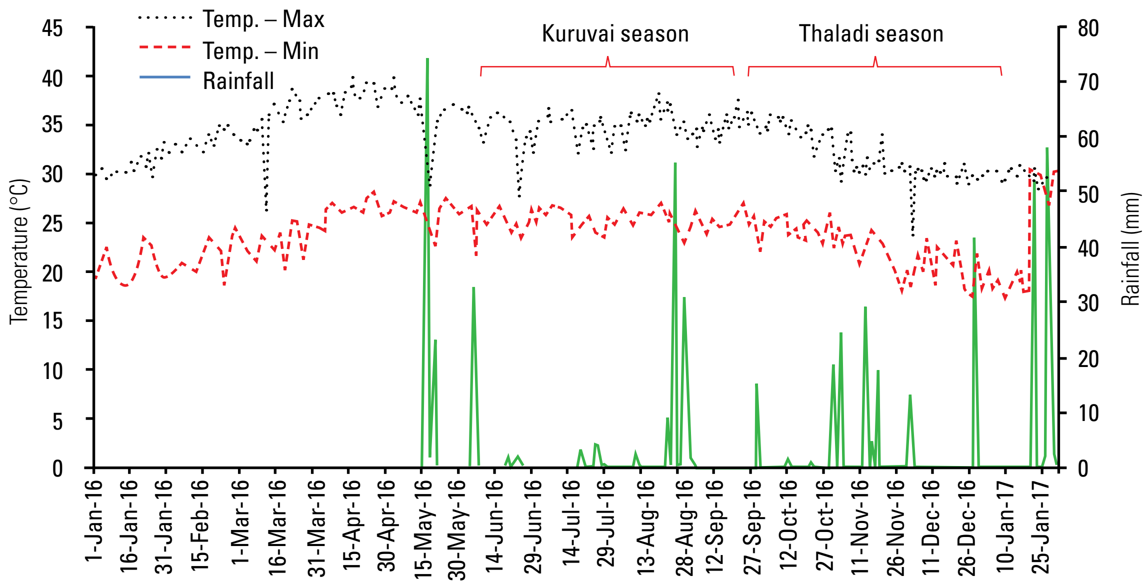


Table 2: Details Rice Plantation and Water/Fertilizer Treatments in the Three Experimental Plots

	Conventional (CT) (ON-CF)	SRI (YW-AWD)	Modified SRI (IB-AWD)
Seedling (days old)	25	8-12	16
Seeding per hill	2-3	1	2-3
Spacing (cm)	10 × 15	25 × 25	25 × 25
Hills per m^2	66	16	16
Irrigation	Continuous flooding	AWD	AWD
Fertilizer	NPK 150:50:50 kg ha^{-1}+ $ZnSO_4$-25 kgha^{-1}+ Gypsum (500 kgha^{-1})		

The soil was classified as alluvial clay comprising total nitrogen (N) 1.1 g kg^{-1}, total carbon (C) 19.6 g kg^{-1}, pH 7.5 (1:5 H_2O) and EC 11.6 mSm^{-1}, 13.6 per cent sand, 61.2 per cent silt and 25.3 per cent clay. The experiment was laid out in a split plot design with three isolated replications of size 7×5 m^2. Two sets of factors included in the experiment were:

- Different planting methods (CT, SRI and MSRI)
- Commonly grown rice varieties (ADT 43 and CO 51 in Kuruvai season and ADT 46 and TKM 13 during Thaladi). *Table 2* provides further details of the experimental design of rice plantation, irrigation and fertilizer[9].

The air samples to measure CH_4 concentrations, used for rice field to atmosphere flux calculation, were taken by using the closed chamber method[10]. The gas samples from all the plots were collected 20 and 22 times during the growing period in Kuruvai and Thaladi season, respectively, under a well-mixed condition (*Figure 3,* page 26). The temperature inside the chamber was recorded at the time of sampling by using a micro-temperature thermometer (PC-9125, AS ONE Co., Tokyo, Japan).

The concentrations of CH_4 were analyzed with a gas chromatograph (GC 2014, Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector (FID) (and for N_2O using an electron capture detector)[11]. The CH_4 fluxes were calculated by examining the linear increases of CH_4 concentrations in the headspace of the chambers over time. The seasonal total CH_4 emissions from all plots were calculated directly from the fluxes.

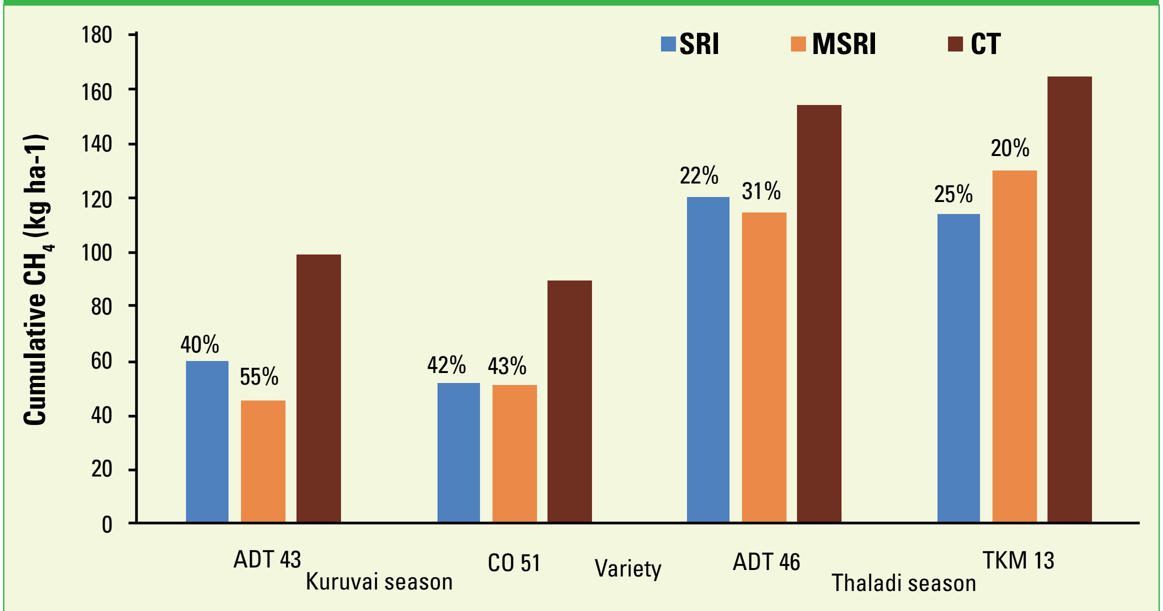
9 Refer. Oo et al., 2018

10 Minamikawa et al., 2015

11 See Oo et al., 2018 for further details

Figure 3: Sampling of air from the flux chamber (seen as white tombs) headspaces through a three-way stop cock using an airtight syringe of 50 ml volume (a; left). Samples were collected at 0, 15 and 30 min after closure of the chambers. The air samples were then transferred to 15 ml vacuum glass vials with rubber stoppers and kept cool and dark till analysis at NIAES, Tsukuba, Japan (b; right).

Figure 4: Cumulative CH_4 emissions as estimated using the flux chamber method at the TRRI experimental site for the 3 rice cultivation practices (CT, SRI and MSRI) and two rice varieties during the two cropping seasons of summer Kuruvai (dry) and Thaladi (wet). The reductions in CH_4 emissions in SRI and MSRI compared to the CT method are given in percentage at the top of the SRI and MSRI bars.



Seasonal changes in CH_4 flux throughout the growing seasons differed among the planting methods. In the Kuruvai season, CH_4 flux increased during early growing period and then gradually decreased to the end of the growing period. The CH_4 flux from CT showed two emission peaks both occurred during vegetative growing period. In SRI and MSRI, high emission peak was observed with the commencement of AWD irrigation.

In the Thaladi season, CH_4 fluxes increased from the beginning and peaked for the first time within two weeks, followed by decreased emission in both rice varieties. Thereafter, CH_4 fluxes from SRI and MSRI increased, peaked for a second time at middle of the growing period and then gradually decreased toward the low emission value on account of AWD irrigation. The CH_4 fluxes from CT also showed high emission peak for the second time and tended to remain high during middle and later growing period. In all planting methods, CH_4 fluxes increased again, peaked for the third time at final stage of growing period and then decreased to lowest value at harvest time due to dry condition.

During Kuruvai, the highest cumulative CH_4 emission was observed in CT (*Figure 4*). The SRI and MSRI reduced cumulative CH_4 emissions by

40 per cent and 55 per cent, respectively, compared to CT. During Thaladi, cumulative CH_4 emissions from SRI and MSRI were significantly ($P<0.05$) lower compared to CT. The reduction in CH_4 emissions by SRI and MSRI were 22 per cent and 31 per cent in ADT 46, and 25 per cent and 20 per cent in TKM 13, respectively, compared to CT.

Cumulative emission between SRI and MSRI was statistically on par and no varietal differences were observed in both crop seasons. Between the Kuruvai and Thaladi seasons, the rate and cumulative CH_4 emissions were higher in the Thaladi season (*Figure 4*). Kuruvai season accounted for 33 per cent and the Thaladi season for 67 per cent of the total emission from double-cropping paddy rice averaged over planting method and rice variety.

Although the date of seedlings transplanted varied with the planting methods, there was no effect on water requirement in either crop season. Water use was mainly influenced by different irrigation management practices among the planting methods. Under AWD irrigation, total water saving from SRI and MSRI was 47.5 per cent and 49.3 per cent in Kuruvai and 79.4 per cent and 79.8 per cent during Thaladi season, respectively, compared to CT (*Table 3*). High water saving in Thaladi was due to high frequent rainfall occurrences that coincided with irrigation time for the SRI and MSRI methods.

A meta-analysis suggested that if AWD is practiced during the wet season, a 25.7 per cent reduction in total water use, which translates into

an even greater reduction in irrigation water use[12].

Table 3 also shows the CH_4 emissions as estimated for the different planting methods. The equivalent CO_2 (CO_2-eq) emission as a measure of the greenhouse gas intensity is calculated using the equation: $CO_2\text{-eq} = TCH_4 \times 34$; where TCH_4 is the total amount of CH_4 emission (kg ha^{-1}) and 34 is the global warming potential for CH_4 relative to CO_2 over a100-year time horizon (as in IPCC, 2013). The results clearly suggest an environmental benefit of SRI (and MSRI) cultivation method through reduction of CH_4 emissions as well as large savings in irrigation water use. These cost reductions

Table 3: Impact of SRI on seed and water savings and CH_4 emissions in Tamil Nadu, India. Scaled up values for 1 mha are also given for showing the advantage of SRI over the CT rice cultivation practice. Total rice cultivation area in India is 43 mha and 2 mha in Tamil Nadu alone.

	Conventional	SRI	Estimate for 1 M ha		Advantage due to SRI
			Conventional	SRI	
Seed used	30 kg ha^{-1}	7.5 kg ha^{-1}	30000 t	7500 t	22500 t
Irrigation water used					
Kuruvai	930 mm	526 mm	3.1 M ft	1.7 M ft	1.4 M ft
Thaladi	488 mm	108 mm	1.6 M ft	0.35 M ft	1.2 M ft
Cumulative CH_4 emission					
Kuruvai	94 kg ha^{-1}	56 kg ha^{-1}	94000 t	56000 t	38000 t
Thaladi	159 kg ha^{-1}	117 kg ha^{-1}	159000 t	117000 t	42000 t
CO_2-eq emission (CH_4 emission × 34)					
Kuruvai	3196 kg ha^{-1}	1904 kg ha^{-1}	3196000 t	1904000 t	1.29 M t
Thaladi	5406 kg ha^{-1}	3978 kg ha^{-1}	5406000 t	3978000 t	1.43 M t

12 Carrijo et al., 2017

Empowering the Farmer with Knowledge

Farmers in Tamil Nadu, where this experiment was conducted, as elsewhere in India are simple, industrious, sincere and honest. Hard work is a given for, apart from the sowing, watering, nurturing and harvesting of crops, they have to prepare the field and get it ready to plant for two to three crops per season. Depending on availability of irrigation water resources, they grow two rice crops followed by pulses within a year. This is clear even without having to interact much with the farmers directly for this project.

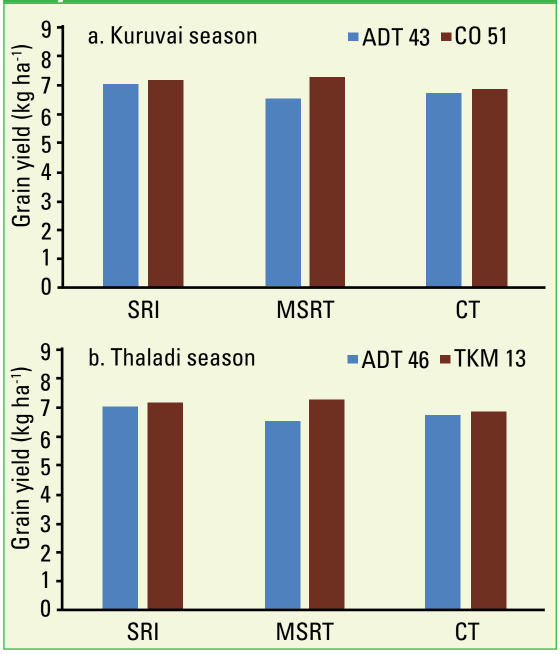
For many good reasons, farmers stick to their traditional methods of farming and are reluctant to change to new approaches for sustainable crop production. The situation becomes complex due to lack of facilities and support to make the transition. Farmers could easily adapt to the water management practice of alternate wetting and drying (AWD) provided there is guaranteed water supply.

In our understanding, they flood the paddy fields by collecting monsoon rain for securing water sufficiency till the time of harvesting. Rice paddies, unlike the wheat or pulses, are tolerant to continuous flooding. Under on-going climate change, scarcity of water for irrigation might affect the farmer's method of rice farming and their livelihood.

In this situation, it is necessary to educate farmers by sharing information like climate-smart agriculture methods. Our research findings might offer a possible solution through practicing System of Rice Intensification (SRI) or modifying this system to local/regional differences in infrastructure such as optimal water saving by the alternate wetting and drying irrigation, depending on rainfall events.

For scientists, it is extremely rewarding when research results are of direct relevance to the society and the global environment, and enhance convenience of the farmers (savings in terms of cost of seeds and irrigation for example). In addition, engaging in field work is a pleasant experience for those who spend long hours in the laboratory. The experience is made richer by the warm welcome and kind hospitality of the host institutions, who at TRRI are also dealing with farmers' well being by producing high-yield grain cultivars and other knowhow.

Figure 5: Rice grain yield observed for the different cultivation methods (CT, SRI, MSRI) and rice cultivars (ADT 43, CO 51, ADT 46, TKM 13) during Kuruvai (dry; a) and Thaladi (wet; b) seasons.



are achievable without compromising on crop yield.

This study observed no significant differences in grain yields in the two crop seasons, grain yield of SRI and MSRI with AWD irrigation was comparable with yield of CT (*Figure 5*). Other studies have showed high grain yield in SRI compared to conventional transplanting for the 'Pusa Basmati 1401' variety[13]. Although such modification of the SRI method as transplanting 16-day old seedlings with 2-3 seedlings per hill was introduced to increase grain yields in both crop seasons, an increase in rice productivity under MSRI depended largely on rice variety (high yield was observed only with CO 51 and TKM 13 varieties under the MSRI method in Kuruvai and Thaladi seasons respectively).

The yield-scaled metric is increasingly used to provide a measure of agronomic efficiency that begins to address both climate change and future food supply concerns. Results from this study clearly showed that the yield-scaled CO_2-eq emission, which integrates the mitigation of GHG emissions while achieving food security, was highest in CT because

13 Suryavanshi et al., 2013

emissions were higher and no significant difference in grain yield compared to SRI and MSRI in either crop season.

Yield scaled CO_2-eq emission from SRI and MSRI was lower due to low CH_4 emission. Therefore, it is strongly recommended that SRI and MSRI methods be adopted for efficient reduction of CO_2-eq emission without reducing grain yield, in comparison with the CT method regardless of the crop seasons/variety.

The seasonal variation in CH_4 emission was influenced by soil environmental factors such as soil redox potential (Eh), water depth and soil temperature in both crop seasons. Negative correlations between CH_4 emissions and soil Eh existed in both crop seasons. Positive correlation between soil temperature and CH_4 emission was observed only in the Kuruvai season, although the temperature range in both crop seasons was higher than the range 15-20°C for triggering CH_4 formation in anaerobic zones of rice soils. Thus, the farmers may also be advised to track their field conditions for maintaining soil quality for sustainable farming under the global change conditions. ●

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